Gyroless Ball: Estimation Of Angular Velocity Without Gyroscope

L Magnis, Nicolas Petit

GYROLESS BALL: ESTIMATION OF ANGULAR VELOCITY WITHOUT GYROSCOPE

L. MAGNIS AND N. PETIT

MINES ParisTech, PSL Research University, CAS - Centre automatique et systèmes, 60 bd St Michel 75006 Paris, France

In [MP15a, MP15b], an algorithm is proposed to estimate the angular velocity of a rigid body using only vector measurements (i.e. measurements of unknown but constant directions). The cases of a single and two vectors measurements have been addressed using similarly structured state-observers.

In this note, we report experiments conducted on one such rigid body, here a wood ball, which is equipped with a smartphone. The direction sensors of the smartphone (magnetometer and accelerometer) are used in the algorithm and the angular rate estimate is compared against the readings from the smartphone gyro. Although neither the magnetic field nor the field sensed by the accelerometer are constant, the estimation algorithm works well.

The experiments were conducted on August 26th, 2015 and have been presented at the Congrès Français de Mécanique 2015. A video can be found on YouTube:

`https://youtu.be/L8fNeH347C8`

1. Sensors

The smartphone under consideration is an Android Nexus 5 which embeds a tri-axis gyros and accelerometers MPU-6500, and a tri-axis magnetometers AK8963. These sensors can be readily seen on the printed circuit board (PCB) of the smartphone, see Figure 1.

The "Sensor Kinetics Pro" Android app allows us to visualize the data produced by the sensors in real-time, to save them and to export them in `.csv` format. Although we do not have access to a data-sheet of the smartphone PCB, pictures of the components and their location on the PCB allows one to roughly identify the sensor axes orientations. As far as we could detect it, the three sensors are aligned and produce data in the body frame represented in Figure 1. The data are time-stamped. The sampling intervals are approximately 0.01 [s]. They vary with the processor usage.

2. Experimental results

We test the angular velocity observer on data produced by the aforementioned sensors. The reference vectors are the gravity field and the magnetic field. The smartphone is inserted inside a wood ball comprising a hole. Figure 2 pictures the smartphone partially inserted. The hole is then plugged with foam to ensure

Date: 07/12/2015.

stability of the smartphone. The rigid body under consideration is the system {ball + smartphone}. This device gives the user a lot of flexibility on the choice of rotation motion, as it can freely roll on the ground, according to its initial conditions.

In details, we implement observer (6) of [MP15b] with a the data produced by the accelerometer, b the data produced by the magnetometer. The tuning parameters are set to $\alpha = 1$, $k = 5$. In the observer implementation, the torque governing the dynamics is arbitrarily set to $\tau = 0$, which assumes that the rigid body is in free-rotation. The inertia matrix is (roughly) estimated to

$$J = \begin{pmatrix} 0.0878 & 0 & 0 \\ 0 & 0.0878 & 0 \\ 0 & 0 & 0.0878 \end{pmatrix} \; [\mathrm{kg.m}^2]$$

In this expression one has neglected the contribution of the smartphone to the matrix of inertia, this corresponds to the inertia of a homogeneous ball of radius 15 [cm] and mass density 0.69.

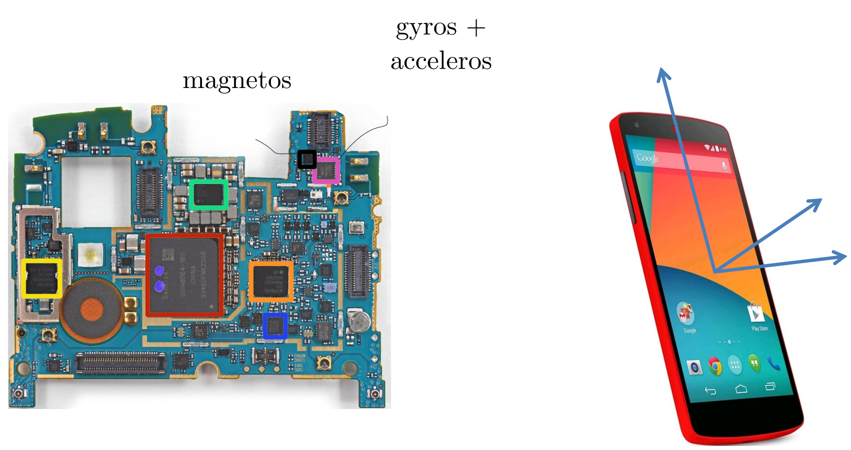

FIGURE 1. Left: printed circuit board of the Android Nexus 5. Identification of tri-axis sensors. Right: the body-frame is aligned with the principal axis of inertia of the smartphone.

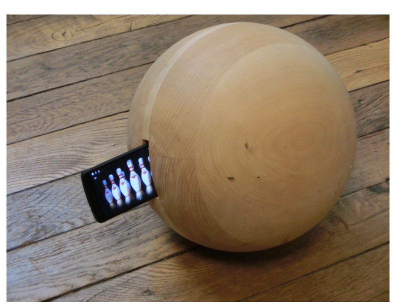

FIGURE 2. The smartphone is to be inserted in a wooden-ball via a hole.

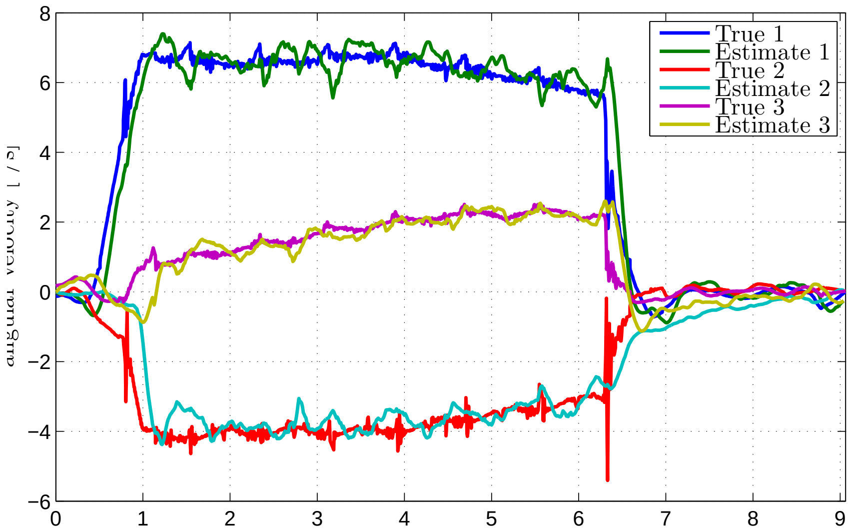

FIGURE 3. Estimation results: observer estimates using only direction sensors versus true angular velocity measured by the embedded gyros.

The ball is then given some initial velocity and left rolling on the ground until it is stopped. Once the data are recovered from the smartphone, they are processed in pseudo real-time (i.e. from initial time to end-time) by the observer. The estimation results can be compared against the measurements of the angular velocity given by the rate gyros of the smartphone. In accordance with the theory, the gyros data are not used in the observer, they only serve as reference for final comparisons.

The estimation results are reported in Figure 3. It appears that the estimates are unbiased (though a bit noisy).
Note: The experimental dataset can be requested to the authors by email.

References

[MP15a] L. Magnis and N. Petit. Angular velocity nonlinear observer from single vector measurements. *Automatic Control, IEEE Transactions on*, PP( ):to appear, 2015.

[MP15b] L. Magnis and N. Petit. Angular velocity nonlinear observer from vector measurements. *arXiv:1503.02870*, 2015.